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ELECTRON BEAM SEMICONDUCTOR DEVICES

FINAL REPORT

10 February 1971 to 19 May 1972

CONTRACT No. DAAB07-71-C-0120

W-J Project No. 22-4087

Prepared by
J. A. Long

September 1972

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Watkins-Johnson Company
3333 Hillview Avenue
Palo Alto, California

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13. ABSTRACT

Work accomplished on Contract DAAB07-71-C-0120 during the period of 10 February 1971 to 19 May 1972 is described in this Final Report. The goal of this program was the evaluation and delivery of certain Electron Beam Semiconductor devices. In Phase A, five Watkins-Johnson Model WJ-3650 pulse amplifiers were fabricated, tested, and delivered. In Phase B, ten Watkins-Johnson semiconductor diodes were fabricated and delivered to ECOM.

Tests performed on the WJ-3650 during Phase A showed that this device is capable of producing single polarity pulses of 150 volts with 1.5 ns risetime and dual polarity pulses for push-pull operation of 225 volts peak-to-peak with 3 ns risetime.

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FINAL REPORT

I. INTRODUCTION

This report is prepared in accordance with the requirements of Contract DAAB07-71-C-0120. It covers the period from 10 February 1971 to 19 May 1972.

The objective of this program, as stated in the U. S. Army Electronics Command Electron Tube Division Technical Guidelines for "Electron Beam Semiconductor Devices" dated 28 August 1970, is to (a) evaluate the capability of an electron beam-semiconductor pulse amplifier for switching repeated short pulses of a few amperes with nanosecond risetime and (b) construct semiconductor diodes for use as an RF amplifier in an electron beam device.

Phase A of the program required the fabrication, testing, and delivery of five Watkins-Johnson Model WJ-3650 pulse amplifiers with an objective output pulse voltage of 200 volts and a risetime of less than one nanosecond into a 25 ohm load. Phase B required the fabrication and delivery of ten Watkins-Johnson electron beam diodes with the N⁻ (drift) layer reduced to 11 micrometers in order to minimize transit time effects at frequencies up to 3 GHz when used in an electron beam-semiconductor amplifier.

Phase A of the program was completed with the delivery of five WJ-3650 pulse amplifiers. Tests performed during this phase showed that this device is capable of producing single-polarity pulses of 150 volts with 1.5 nanosecond risetime and dual polarity pulses for push-pull operation of 225 volts peak-to-peak with 3 ns risetime.

Phase B of the program was completed with the delivery to ECOM of ten semiconductor diodes mounted on studs.

2. DEVICE DESIGN AND FABRICATION

The WJ-3650, used in Phase A, is an Electron Bombarded Semiconductor Video Pulse Amplifier having the specifications shown on the Developmental Specification Sheet of Appendix 1.

The diodes delivered in Phase B are identical in size to those used in the WJ-3650 but are modified in thickness and resistivity.

2.1 WJ-3650 Design and Fabrication

The WJ-3650 consists of a circular-beam electron gun, shown in Figure 1, a meander line deflection structure shown in Fig. 2 and a semiconductor target shown in Fig. 3. The semiconductor diodes which are fabricated by Signetics are interconnected for Class B operation. Each diode used in the WJ-3650 has an N^- (drift) region that is 50 micrometers thick with a resistivity of 38 ohm-cm. The size of the active area is 1.0 mm x 2.5 mm or 2.5 mm². These diodes were passivated with a 3 micrometer layer consisting of 1 micrometer of thermally grown oxide and 2 micrometers of phosphorous glass. A drawing of the WJ-3650 target is shown in Fig. 4.

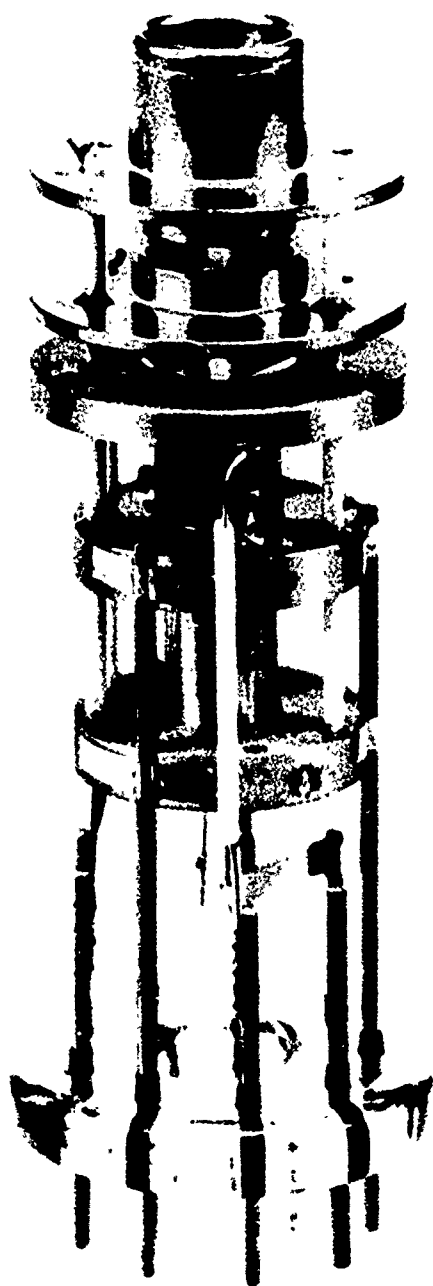
Figure 5 shows the WJ-3650 after pumping and cathode processing and prior to casing. The electron gun can be seen through the glass bulb at the left and the RF output connector is at the right. The left hand connector on top is the RF input and the right hand connector is the output of the deflection structure which is normally terminated.

The cased WJ-3650 is shown in Fig. 6.

2.2 Diode Design and Fabrication

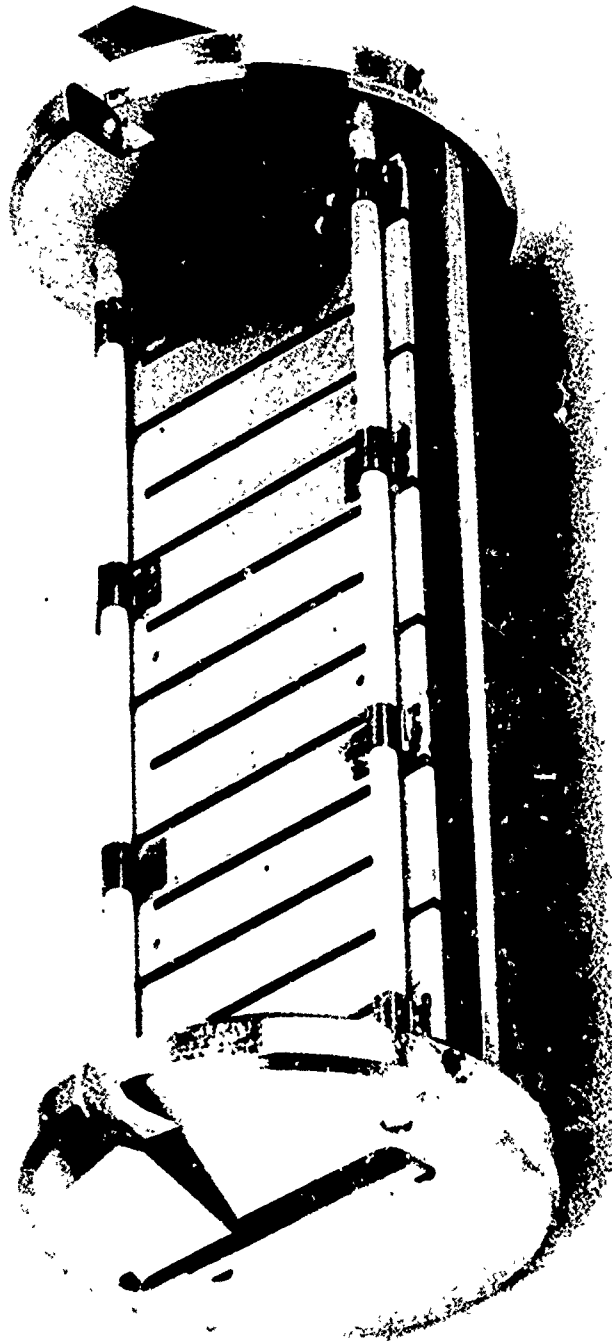
The diodes delivered under Phase B of the program were designed at Watkins-Johnson and fabricated by Signetics. These diodes have the same active area, 2.5 mm², as those used in the WJ-3650 but the diode thickness and the resistivity were changed as specified in the Technical Guidelines. Thickness of the N^- region is 11 micrometers and the resistivity is 22 ohm-cm. The surface passivation was unchanged from that used in the WJ-3650.

Ten of these diodes were mounted on especially designed studs and delivered to ECOM.



8408-1

Fig. 1 - Circular beam electron gun.



8408-3E

Fig. 2 - Meander line deflection structure.

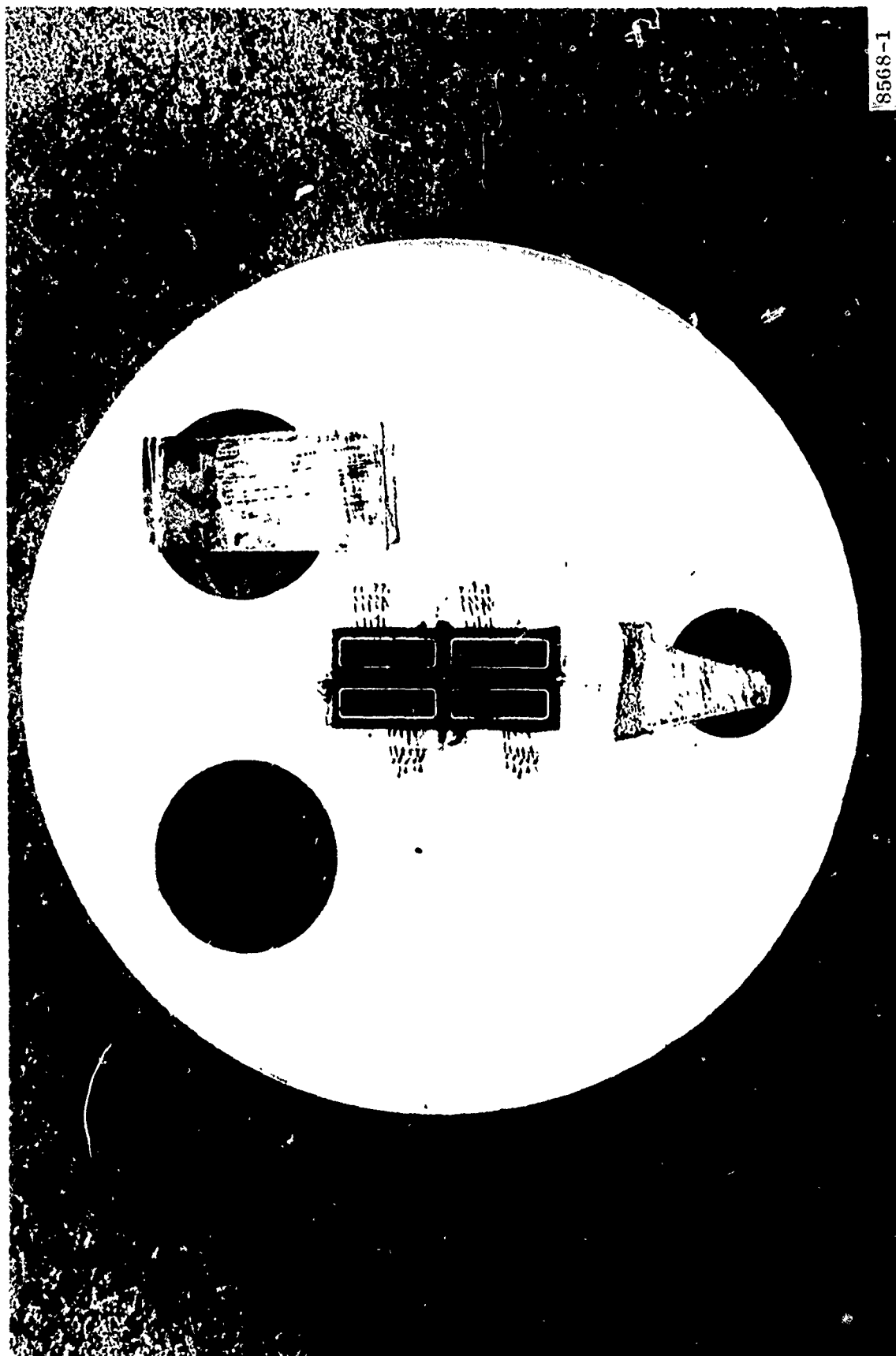


Fig. 3 - WJ-3650 Semiconductor Target.

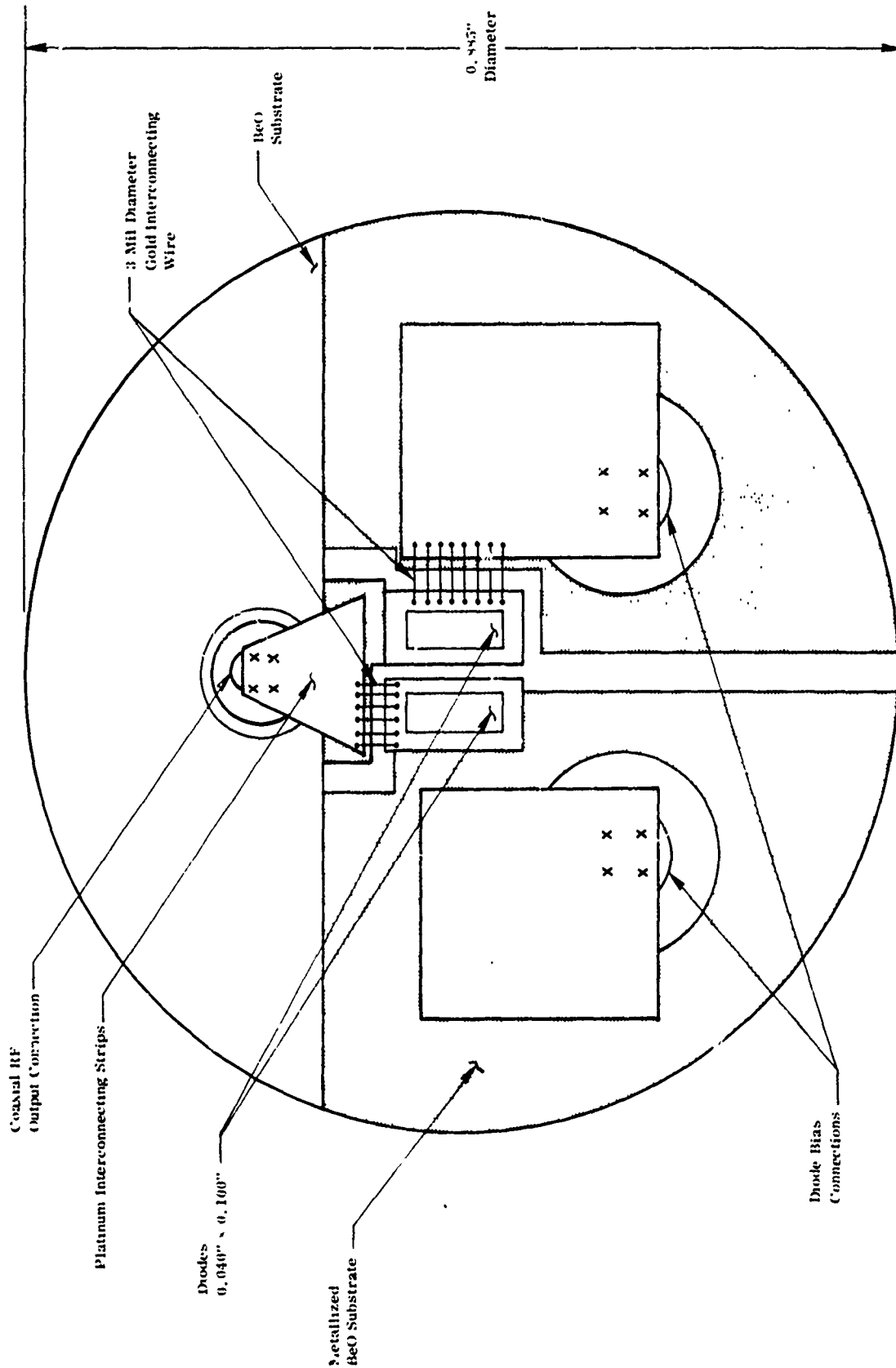


Fig. 4 - Drawing of the WJ-3650 Target.

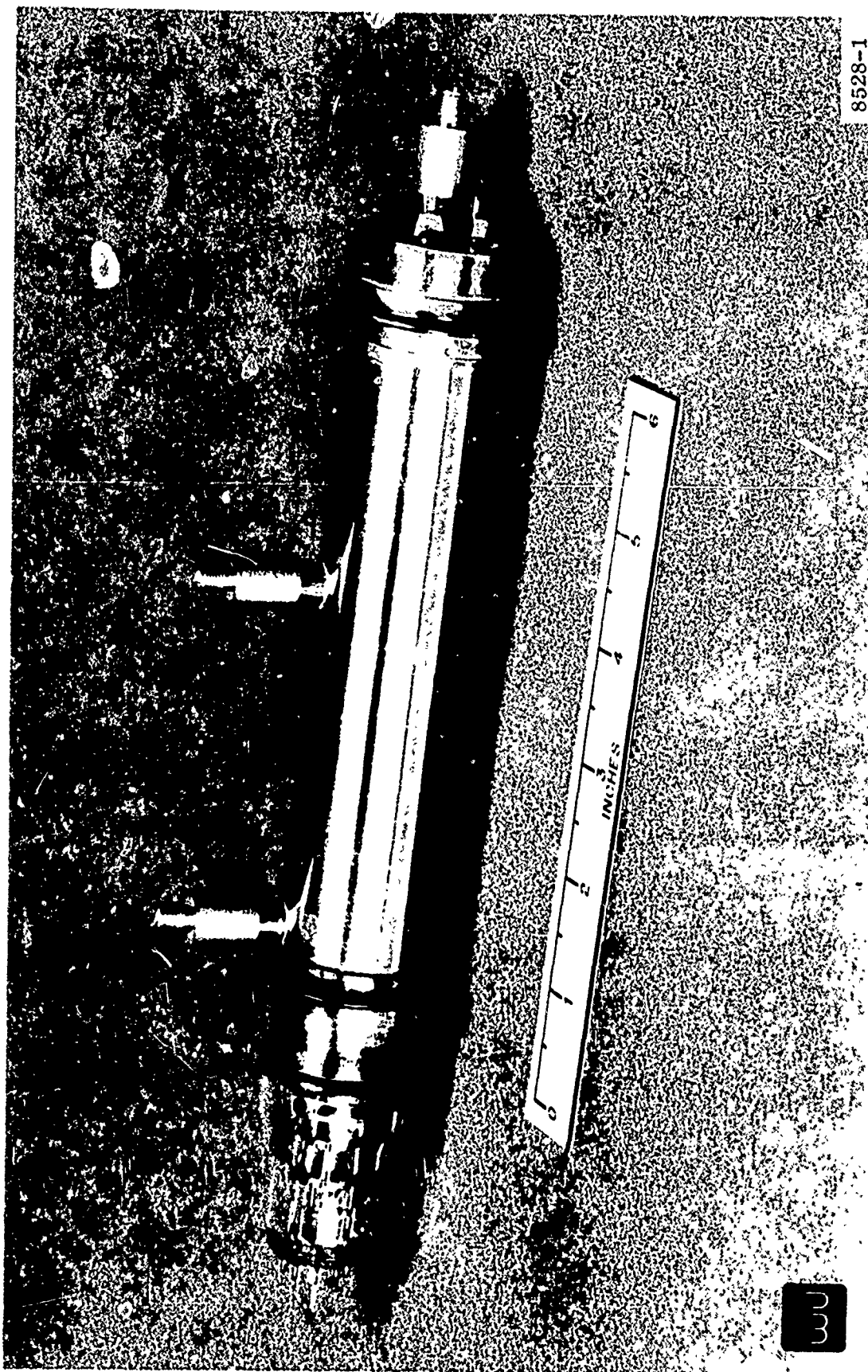


Fig. 5 - WJ-3650 (uncased).



Fig. 6 - Photograph of WJ-3650 deflected beam EBS amplifier.

8428-1



3. DEVICE TESTING

All five WJ-3650 pulse amplifiers were tested prior to delivery to ECOM. The ten diodes were tested for their voltage breakdown characteristics before delivery.

3.1 WJ-3650 Testing

The five WJ-3650 pulse amplifiers that were delivered were tested for their performance characteristics prior to shipment. The results of these tests are summarized in Table I.

Characteristic	WJ-3650 Serial No.				
	6	8	9	10	11
1. Pulse Output Voltage					
A. Positive (volts)	150	160	120	105	120
B. Negative (volts)	150	160	120	105	120
2. Pulse Risettime (ns)	1.5	1.5	1.5	1.5	1.5
3. Input Voltage (volts)	7.0	10	10	10	10
4. Duty Cycle (percent)	2	2	2	2	2

Table I - Summary of Final Test Data on the five deliverable WJ-3650's. Load impedance was 50 ohms.

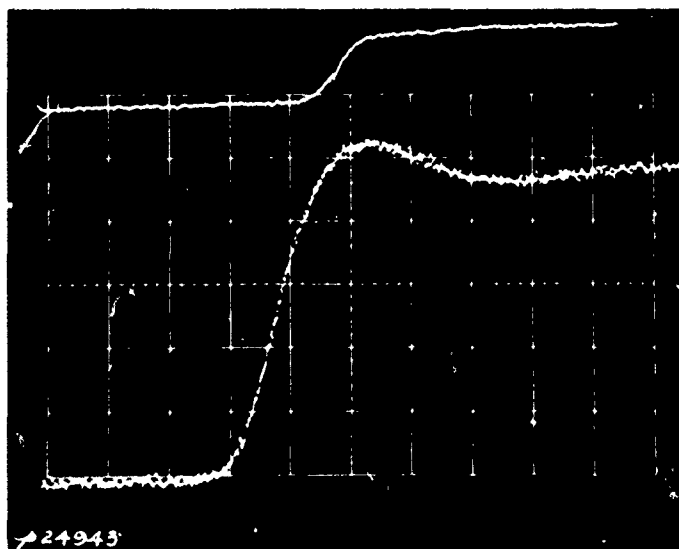
The pulse voltages listed above are all for single polarity pulses.

In addition, tests were made of the pulse output characteristics when operated in the dual polarity or push-pull mode into both 50 and 25 ohm terminations.

Figure 7 shows photographs of sampling scope traces of the input and output pulses for a WJ-3650 operating into 50 ohms in the top photograph and 25 ohms in the lower one. The upper trace in each photograph is the input pulse and the lower trace is the output. In both cases the output is operated in the dual polarity or push-pull mode. This means that with no drive the amplifier is putting



Time Base: 4 ns/cm.



Time Base: 1 ns/cm.

Fig. 7 - Comparison of input and output pulse risetimes of the WJ-3650 EBS amplifier with 50 and 25 ohm load impedances, respectively. The vertical scope sensitivity is 10 volts per centimeter for the upper (input) traces in both photographs and 50 and 40 volts respectively for the lower (output) traces.

out a negative voltage of approximately one-half of the total pulse voltage. When the input pulse is applied the output starts at a negative voltage, goes to a positive peak and then returns to the original negative value. In this mode, a substantially greater voltage pulse can be achieved than is possible in the single polarity mode.

In the upper photograph, operating into a 50 ohm load, the output pulse voltage is 225 volts and the pulse risetime is 2.2 nanoseconds when the input pulse risetime of 1.0 nanosecond is subtracted.

In the lower photograph, operating into a 25 ohm load the output pulse voltage is approximately 200 volts with a risetime of 1.0 nanoseconds when the input pulse risetime is taken into account.

The total signal delay through the WJ-3650 was measured to be slightly less than 3 nanoseconds.

3.2 Diode Testing

The ten diodes delivered to ECOM were each tested for its voltage breakdown characteristics prior to shipment. The voltage at the 100 microampere point for the diodes is shown in Table 2, below.

<u>Diode No.</u>	<u>Voltage at 1.0 mA</u>
1	160 volts
2	150 volts
3	145 volts
4	160 volts
5	130 volts
6	140 volts
7	150 volts
8	150 volts
9	145 volts
10	145 volts

Table II - Voltage breakdown characteristics of the ten diodes.

A typical diode oscillogram of diode current versus reverse bias voltage is shown in Fig. 8.

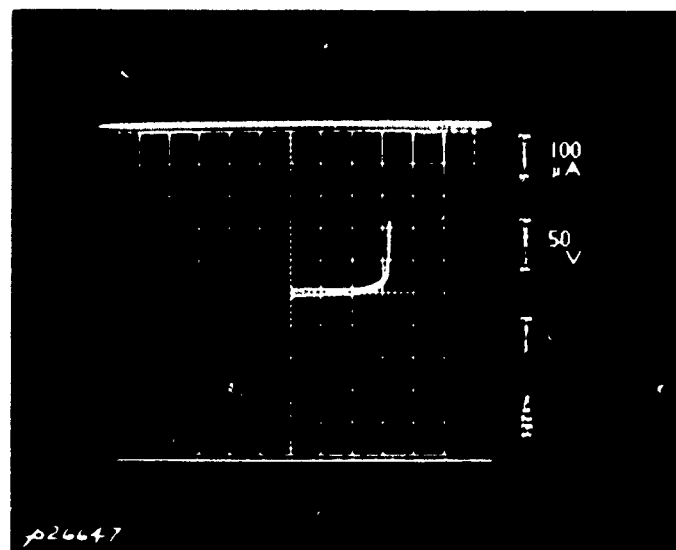


Fig. 8 - A typical diode oscillogram of diode current versus reverse bias voltage.

4. SUMMARY AND CONCLUSIONS

This program was divided into two phases. The objective of Phase A was the fabrication, testing, and delivery of five WJ-3650 pulse amplifiers. During Phase B, ten diodes were to be fabricated and delivered. During Phase A, eleven WJ-3650 amplifiers were built and tested and five were delivered.

Typical performance characteristics for the delivered WJ-3650 amplifiers were:

Pulse Output Voltage	150 volts
Pulse Risettime	1.5 nanoseconds
Input Voltage	10 volts
Duty Cycle	2 Percent

During Phase B, twelve single diodes fabricated and ten were delivered, mounted on studs. A typical voltage breakdown for these ten diodes is 140 volts.

APPENDIX I

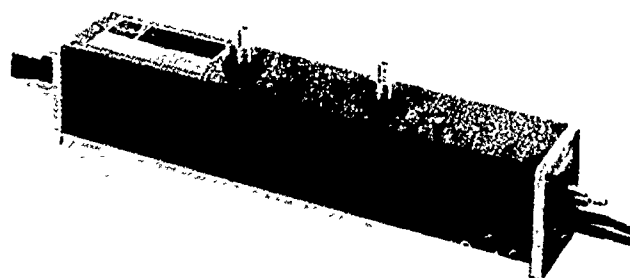
WJ-3650 TECHNICAL DATA SHEET

TECHNICAL DATA



WATKINS JOHNSON

ELECTRON BOMBARDED SEMICONDUCTOR (EBS) RF AND VIDEO PULSE AMPLIFIER WJ-3650



- PULSE OUTPUT VOLTAGE 250 VOLTS (DUAL-POLARITY)
- PULSE RISETIME LESS THAN 2 NANOSECONDS
- PEAK POWER OUTPUT 125 WATTS AT 27 dB GAIN

The WJ-3650 is one of a new series of Watkins-Johnson Electron Bombarded Semiconductor (EBS) components. This device amplifies pulses of either polarity and delivers an amplified voltage output pulse with nanosecond risetimes. Alternatively, it can be used as an RF amplifier to produce a peak power output greater than 125 watts (50 ohm load) and wide instantaneous bandwidth.

The WJ-3650 utilizes an electron beam that passes through a wideband deflection system. An input signal deflects the electron beam between two silicon semiconductor diode targets. Since the pair creation energy of a silicon semiconductor lattice is 3.6 eV, each 10 keV incident beam electron produces thousands of carrier pairs, resulting in a current gain of about 2000. In the absence of an input signal, no beam cur-

rent is intercepted by the diodes and thus no output signal results.

For maximum efficiency, a voltage swing across the diode from zero to the maximum output voltage is desirable. This will result in the positive half of the sine wave being completely intercepted by one target and the negative half of the sine wave intercepted by the other target. Efficiencies as high as 50% have been measured.

The basic frequency response of the WJ-3650 is that of a broadband low pass amplifier. This response is largely limited by the capacitance of the diode and the load impedance. The transit time of the carrier pairs through the diode also has an effect. Pulse risetimes of 1.0 nanosecond are attained into a 25 ohm load.

SPECIFICATIONS

PERFORMANCE CHARACTERISTICS	Fast Rise Mode	High Voltage Mode
	(Load Impedance: 25 ohms)	(Load Impedance: 50 ohms)
Time Domain		
Video output voltage	190 volts	250 volts
Pulse risetime	1 nanosecond	2 nanoseconds
Video input voltage	10 volts	10 volts
Pulse polarity	Dual polarity ¹	Dual polarity ¹
Duty factor	4 percent	4 percent
Frequency Domain		
RF output power	175 watts	125 watts
Frequency response (3 dB)	DC — 320 MHz	DC — 160 MHz
RF input power	0.25 watts	0.25 watts
Power gain	28.5 dB	27 dB
Duty factor	2 percent	2 percent

WJ-3650

SPECIFICATIONS (Cont'd)

ELECTRICAL REQUIREMENTS

Heater voltage ac	5.0 volts	5.0 to 6.0 Vac
Heater current	0.8 A	0.6 to 1.0 A
Cathode voltage ⁴	-15 kV	-12 to -15 kV
Cathode current	5 mA	2 to 5 mA
Grid bias voltage ²	-150 volts	-140 to -180 V
Grid pulse voltage ³ (peak)	135 volts	130 to 180 V
Grid current	less than 5 μ A	0 to 5 μ A
Anode 1 voltage ²	550 volts	500 to 700 V
Anode 1 current	less than 5 μ A	0 to 5 μ A
Anode 2 voltage ²	1500 volts	1400 to 2000 V
Anode 2 current	less than 5 μ A	0 to 5 μ A
Target 1 voltage ⁴	+200 volts	150 to 250 V
Target 2 voltage ⁴	-200 volts	-150 to -250 V
Targets 1 and 2 current (peak)	7.5 A	5 to 9 A

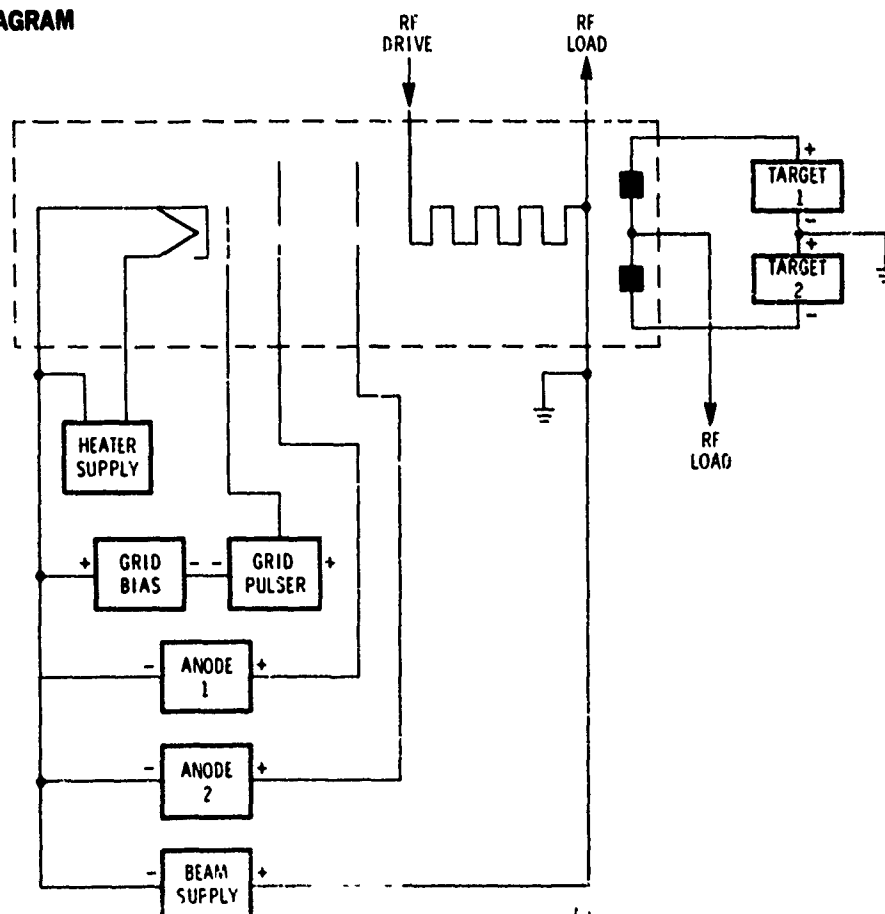
MECHANICAL CHARACTERISTICS

Length	10.75 inches (273 mm) max. (excluding connectors)
Cross section	2 x 2 inches (51 x 51 mm) (excluding connectors)
Weight	3 lbs. (1.36 kg)
Connectors	SMA, Jack
Cooling	Conduction through baseplate

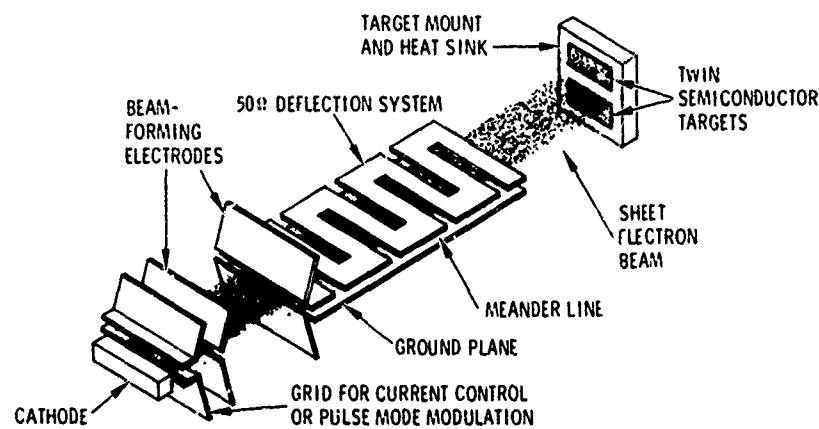
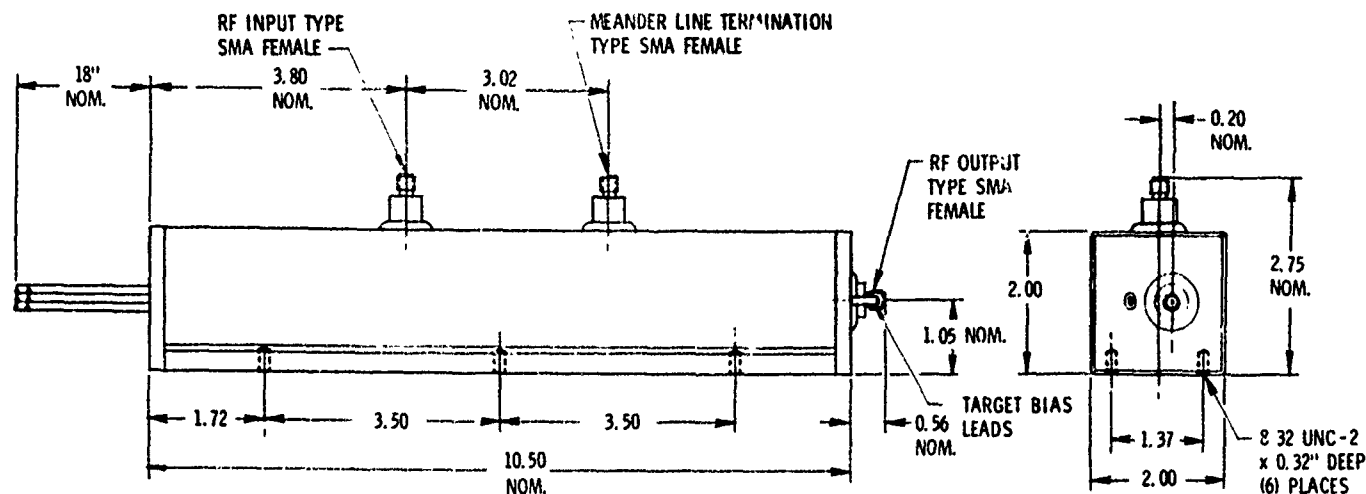
NOTES:

- Both plus or minus output voltage can be obtained.
- Indicated voltages are with respect to cathode. Body is at ground potential.
- Indicated voltages are with respect to the grid bias voltage.
- Indicated voltages are with respect to ground potential.

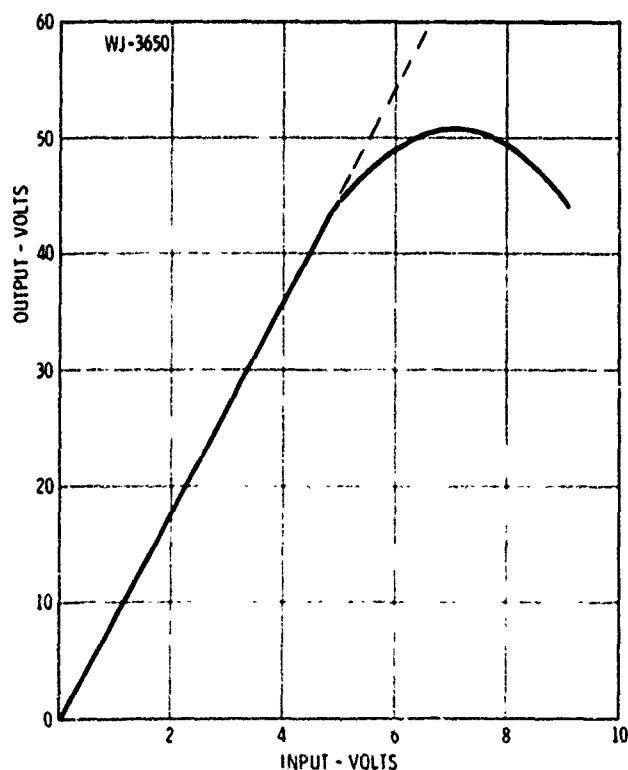
SCHEMATIC DIAGRAM



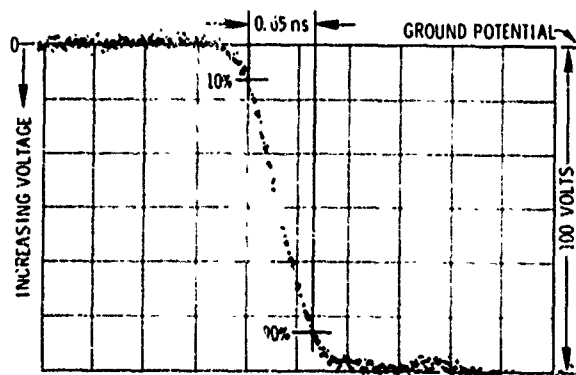
OUTLINE DRAWING



Schematic of the balanced twin-target EBS amplifier using deflection modulation.

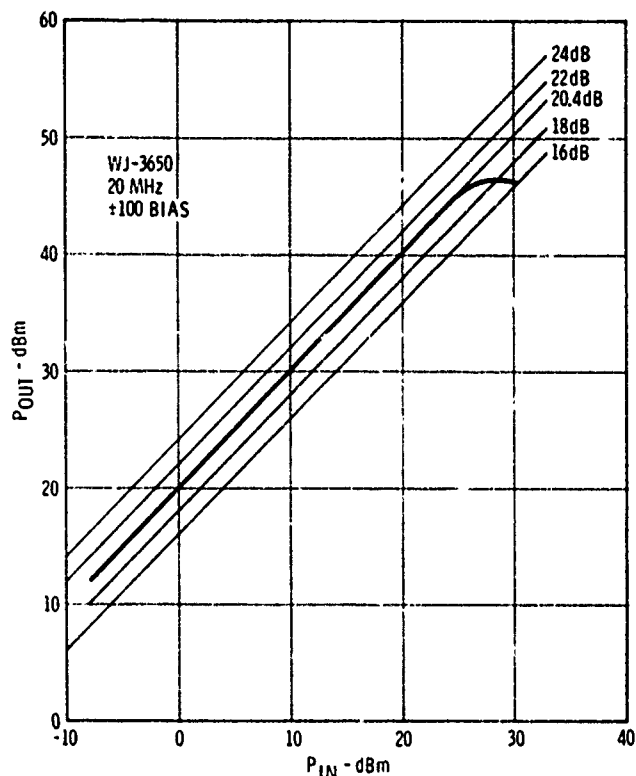


Output voltage of WJ-3650 as a function of input voltage. Note linearity up to saturation point.

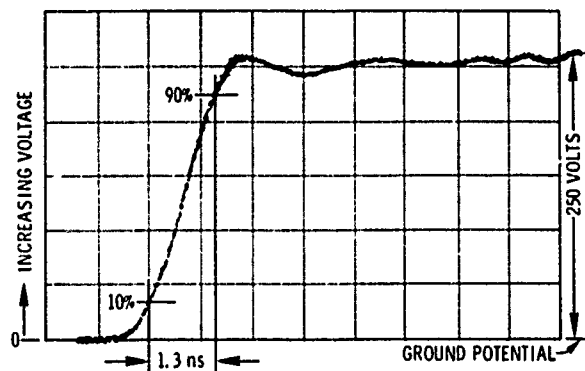


Actual data of response to an input pulse of 6.0 volts, with a single diode target. Output risetime is 0.65 nsec., since only one-half the dual target capacitance is present.

WJ-3650



Output power for the WJ-3650 as a function of input power. Note linearity.



Actual data of response to 10 volt input pulse; 1 nsec risetime. Output risetime is 1.3 nsec.

TABLE OF WATKINS-JOHNSON ELECTRON-BOMBARDED SEMICONDUCTOR APPLICATION NOTES:

Device Delivers kW Output in Picoseconds — No. 100273

The Capabilities of Electron-Beam Semiconductor Active Devices — No. 100274

A Comparison of Electron-Beam Semiconductor Devices Employing Grid Modulation and Beam Deflection — No. 100275B

The Capabilities of Simple Electron-Beam Semiconductor Linear-Switching Devices — No. 100276A

A Picosecond-Risetime Real Time Sampling Element Based on the EBS Interaction — No. 100280A

Characteristics of an EBS RF Amplifier — No. 100336

A Kilowatt-Pulsed RF Electron-Beam Semiconductor Amplifier — No. 100352

Design and Performance of Deflected Beam, EBS Amplifiers — No. 100353D

New Solid State Devices Evolve 100365

EBS Amplifiers Debut 100368

Recent Improvements to Semiconductor Targets Reliability and Performance of the WJ-3650 EBS Video Pulsed Amplifier — 100398

Character of WJ-3652 High Speed EBS Switch for Modulation of Injection Lasers — 100421

EBS Devices — 100423

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Semiconductor						
Electron Beam						
Electron Bombarded						
Video Pulse Amplifier						
Beam Deflection Structure, Meander Line						
Diode						
PN Junction Passivation						

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